

AD

TECHNICAL REPORT ARBRL-TR-02485

GRID NETWORK GENERATION WITH ADAPTIVE
BOUNDARY POINTS FOR PROJECTILES AT
TRANSONIC SPEED

Chen-Chi Hsu

April 1983



US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

Approved for public release; distribution unlimited.

Destroy this report when it is no longer needed.
Do not return it to the originator.

Additional copies of this report may be obtained
from the National Technical Information Service,
U. S. Department of Commerce, Springfield, Virginia
22161.

The findings in this report are not to be construed as
an official Department of the Army position, unless
so designated by other authorized documents.

*The use of trade names or manufacturers' names in this report
does not constitute indorsement of any commercial product.*

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TECHNICAL REPORT ARBRL-TR-02485	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) GRID NETWORK GENERATION WITH ADAPTIVE BOUNDARY POINTS FOR PROJECTILES AT TRANSONIC SPEED		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Chen-Chi Hsu		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Ballistic Research Laboratory ATTN: DRDAR-BLL Aberdeen Proving Ground, Maryland 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1L161102AH43
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Armament Research & Development Command US Army Ballistic Research Laboratory (DRDAR-BLA-S) Aberdeen Proving Ground, MD 21005		12. REPORT DATE April 1983
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		13. NUMBER OF PAGES 35
		15. SECURITY CLASS. (of this report) Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE		
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release, distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Computational Aerodynamics Transonic Flow Projectile Aerodynamics Elliptic Grid System Hyperbolic Grid System Adaptive Boundary Grid Points		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The existing grid generation package GRIDGEN for projectile aerodynamics problems has been modified for an additional option to provide grid systems with adaptive boundary grid points. An improvement on hyperbolic grid generation is also made for more accurate finite-difference computations. The modifications made to GRIDGEN have been discussed and documented. The resulting package of computer programs named ADAPTGD has been tested successfully for generating a number of two-dimensional grid networks for a projectile.		

TABLE OF CONTENTS

	<u>Page</u>
LIST OF ILLUSTRATIONS.....	5
LIST OF TABLES.....	7
I. INTRODUCTION.....	9
II. IMPLEMENTATION TO GRIDGEN.....	9
A. Input Data.....	10
B. Program MAIN.....	10
C. Subroutine OUTER (---).....	10
III. SUBROUTINE HADAPT (F, X, Y, JI, JE).....	11
IV. OTHER MODIFICATION TO GRIDGEN.....	12
V. GRID NETWORK GENERATED BY ADAPTGD PACKAGE.....	12
VI. CONCLUSIONS.....	13
APPENDIX A: PARTIAL PROGRAM LISTING.....	23
PROGRAM MAIN.....	26
SUBROUTINE OUTER (- - -).....	28
SUBROUTINE RHS (- - -).....	29
SUBROUTINE HADAPT (- - -).....	30
FUNCTION ATKN (- - -).....	32
DISTRIBUTION LIST.....	33

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	A Hyperbolic Grid Network Obtained From Original GRIDGEN.....	14
2	A Hyperbolic Grid Network Obtained From Modified GRIDGEN.....	15
3a	An Elliptic Grid Using ADAPTGD - Total Flow Field.....	16
3b	Detailed Elliptic Grid Near Body Surface.....	17
4a	A Hyperbolic Grid Using ADAPTGD - Total Flow Field.....	18
4b	Detailed Hyperbolic Grid Near Body Surface.....	19

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Data File FOR007 for Adaptive Boundary Grid Point Distribution.....	20
2	Input Data for Generating Figure 3a by ADAPTGD.....	21

I. INTRODUCTION

In the field of computational mechanics it is well known that the accuracy of finite-difference approximations depends on the fineness of the grid system; moreover, the accuracy of solutions also depends upon the resolution of solution gradients. For use of a uniform grid system the local truncation error in the difference approximation to derivatives can be the largest at the location where the solution gradient is the largest. Hence, one can expect to obtain greater overall accuracy for the solution if more grid points are concentrated at places where the solution gradient is very large.

For a transonic viscous flow past a slender projectile with sting, the variation of the solution characteristics in the direction normal to the body surface is somewhat predictable qualitatively for most of the flow region; consequently, a rather well-suited grid size distribution in the normal direction can be predetermined and fixed. However, the solution characteristics of a transonic flow problem in the streamwise direction are more complex; the location of nearly normal shocks changes with the value of free-stream Mach number as well as with the number of iterations used in the process of convergence. It is known that in association with the formation of shock waves there exist extremely steep solution gradients. Therefore, a proper distribution of the boundary grid points can be very crucial to the accuracy of the computed forces acting on the projectile in transonic flows.

For an axisymmetric flow, the grid system generation code available at BRL can provide a good grid network for the transonic flow problem if the boundary grid points are properly generated. Presently, the boundary points required for the grid generation are specified and clustered in accordance with the user's intuition and experience; the resulting grid systems have provided accurate results for a number of different flow conditions. It seems, however, that the accuracy and efficiency of the solution method can be further improved if the boundary grid points required for grid generation are adaptively determined according to a relevant solution gradient distribution along the body surface. Moreover, for certain flow problems, the development of an adaptive boundary grid point generation is essential for improving the overall accuracy of solutions, for the maximum number of boundary points allowable in numerical simulation is often limited by the capacity of an existing computer system.

The objective of this development is to modify the existing grid generation code GRIDGEN so that the user will have an option to generate the boundary grid points adaptive to an input control function. The resulting grid generation code named ADAPTGD has been tested successfully.

II. IMPLEMENTATION TO GRIDGEN

In modifying GRIDGEN for adaptive boundary grid point generation, efforts have been made to minimize the changes. In fact, only insertions of executable statements are made to GRIDGEN; consequently, the resulting grid generation code ADAPTGD will make a number of unnecessary computations in the process of redistributing the boundary grid points. A substantial modification not related to the adaptive boundary grid generation has been made to subroutine

RHS (---) so that the resulting hyperbolic grid system exhibits more desirable characteristics for finite-difference computations. The modifications made to GRIDGEN and the relevant information required for using ADAPTGD are described and discussed in the following sections.

A. Input Data

In order to run the grid generation code ADAPTGD, the user must provide two data cards in addition to the regular input data file for GRIDGEN at the very beginning of the input data file. The data cards provide information and instruction for the redistribution of boundary grid points. Definition and comments for the input data can be found in the first part of the program MAIN in ADAPTGD. A listing is provided in Appendix A.

B. Program MAIN

Only insertions of executable statements have been made to the program MAIN of GRIDGEN. The first two executable statements now read the two additional input data cards. The program then continues as before to generate inner boundary grid points by calling appropriate subroutines. However, the generated boundary grid points will be overridden if the user calls for an adaptive boundary grid point generation.

In order to generate adaptive boundary grid points, a tape or file FOR007 which contains the grid points to be redistributed as well as the control function (e.g., pressure) at grid points must be provided. The tape FOR007 must be written in the format

FORMAT (1H ,I5,5E15.7)

and contains, in order, the variables

J, XX(J), YY(J), XS(J), YS(J), FF(J)

where XX(J) and YY(J) are the coordinates of Jth grid point on the inner boundary, while XS(J) and YS(J) are those of the outer boundary. FF(J) is the value of the control function (e.g., computed pressure on the body) at Jth node. The redistribution of the inner boundary grid points and the outer boundary grid points are determined according to a linear function of the gradient of FF(J) by calling the subroutine HADAPT (---), which is described in Section III. Note that the same control function is used for both inner and outer boundary grid points redistribution.

C. Subroutine OUTER (---)

In GRIDGEN the subroutine OUTER is called upon to generate outer boundary grid points for elliptic grid generation. If adaptive boundary grid points are called for a grid generation, then the call for subroutine OUTER can be avoided. In order to maintain the versatility of ADAPTGD to reproduce the capability of GRIDGEN as well as to maintain the format of input data file used in GRIDGEN, the call for subroutine OUTER by subroutine ELPGRD has not been modified; however, if an adaptive boundary grid point distribution is called for a grid generation, then the final computation for XS(J) and YS(J)

in subroutine OUTER is bypassed. Hence, the adaptive outer boundary grid points generated earlier are intact for an elliptic grid generation. Only one COMMON statement and one IF statement have been added to the original subroutine OUTER.

III. SUBROUTINE HADAPT (F, X, Y, JI, JE)

The subroutine HADAPT (---) is developed for the redistribution of nodal points $(X(J), Y(J))$ on a segment of curve (e.g., inner or outer boundary) between nodes JI and JE according to the characteristics of an input control function $F(J)$ along the curve. The redistribution of the nodal points can be iterated for INO times; the iteration is desirable if the discrete value of the control function is used for determining the new nodal point distribution. Consequently, an interpolation function subprogram ATKN (---) has been called by subroutine HADAPT to provide more accurate values for $F(J)$ at the new location. Note that $INO = 3$ has been set in the current version of subroutine HADAPT, which has been found by a number of numerical experiments to be a good choice.

The theoretical background for the subroutine HADAPT (---) is briefly given in the following. Let s be the distance measured along a curve in xy -plane. Assume that a segment of the curve is divided into n elements with node at s_j or (x_j, y_j) for $i = 1, 2, \dots, n+1$. Suppose that $f(s)$ is the control function for element size distribution on the segment, in the sense that higher resolutions are required for higher gradient of $f(s)$. It is then assumed in subroutine HADAPT (---) that the element size must be inversely proportional to a linear function of $\frac{df}{ds}$ for an adaptive nodal point distribution. Therefore, one has

$$\Delta s_j \equiv s_{j+1} - s_j = \frac{\alpha}{1 + \beta \left(\frac{df}{ds}\right)_j} \equiv \alpha w_j \quad (1)$$

where α is the proportional constant and β is the weight parameter for the gradient of control function $f(s)$.

The proportional constant α is determined by equating the sum of n elements to the total segment length. Hence, one obtains

$$\alpha = (s_{n+1} - s_1) / \sum_{j=1}^n w_j \quad (2)$$

With the input data $f_j \equiv f(s_j)$ and (x_j, y_j) at nodes, the gradient of $f(s)$ for a given element Δs_j can be approximated by

$$\left(\frac{df}{ds}\right)_j \approx (f_{j+1} - f_j)/\Delta s_j, \Delta s_j = [(x_{j+1} - x_j)^2 + (y_{j+1} - y_j)^2]^{1/2} \quad (3)$$

The value for $\beta \equiv BW$ can be selected by the user. It is clear that a constant element size distribution will result if one chooses to set $\beta \equiv BW = 0$. It is mentioned in passing that the ratio of the largest element to the smallest element increases with increasing value of β . A value of $\beta \rightarrow BW = 5.0$ has been set in the current version of the program. Note that higher resolutions for the highest gradient region can be achieved by taking a larger value of β , but then poor resolutions will result in the smallest gradient region if the number of nodal points on the line segment of interest is fixed.

The function subprogram ATKN (---) called by subroutine HADAPT (---) is a general purpose interpolation program for one-dimensional problems. Both subprograms HADAPT (---) and ATKN (---) which are placed at the end of ADAPTGD package are also given in Appendix A for reference.

IV. OTHER MODIFICATION TO GRIDGEN

The hyperbolic grid network generated from GRIDGEN for a projectile has some undesirable characteristics in the region upstream of the nose. For example, Figure 1 shows rather large grid sizes upstream of a projectile nose and, consequently, poor orthogonal characteristics at the line of symmetry result. The objective of this modification is then to reduce the size of those large grids as well as to improve their orthogonal property at the line of symmetry.

In GRIDGEN the subroutine RHS (---) is called upon by subroutine HYPGRD (---) to provide the right-hand side of the reduced finite difference equations for hyperbolic grid generation. The subroutine RHS (---) has been modified, after a number of numerical experiments, by introducing a weight function for controlling the area of the grid network. With the same input data of Figure 1, the modified GRIDGEN produces a hyperbolic grid network shown in Figure 2. It is clear that the modified subroutine RHS (---) does give a more desirable hyperbolic grid network for projectile aerodynamics computations.

V. GRID NETWORK GENERATED BY ADAPTGD PACKAGE

The modified GRIDGEN named ADAPTGD has been tested successfully for generating a number of two-dimensional grid networks for a projectile. In these numerical experiments the same tape file FOR007, which is given in Table 1, for controlling the boundary grid point distribution has been employed. The control function FF(J) used is the discrete value of a computed pressure coefficient distribution on a projectile and the size of grid network chosen is 60 by 28. Two of the grid networks generated are presented and discussed briefly in the following.

An elliptic grid network generated with the adaptive boundary grid points is shown in Figures 3(a) and 3(b). The input data used for the grid system

are given in Table 2. Recall that only the first two lines of the data file are new to the data file for GRIDGEN. In the first line the first integer "1" implies that adaptive boundary grid points are called for the grid network generation while the second integer "4" indicates that there are four segments of boundary grid points with segment end points fixed to be redistributed. The starting point and the ending point of each segments selected for redistribution are specified in the second line of the input data file. As indicated in the input data file, the first four boundary points from the nose of the projectile have not been moved; it shows that the user can choose rather arbitrarily any segments of boundary points for redistribution.

The same input data have also been employed to generate a hyperbolic grid network with adaptive boundary points; the resulting grid network is given in Figures 4(a) and 4(b) for reference. The comparison of Figure 4(b) against Figure 3(b) shows clearly that the hyperbolic network has better overall orthogonality characteristics which can be advantageous to the accuracy of solutions to be obtained in the transformed space.

VI. CONCLUSIONS

The modification of GRIDGEN for generating grid networks with adaptive boundary grid points specified has been described. The resulting package of computer programs named ADAPTGD has been tested successfully for two-dimensional straight ray grid systems, elliptic grid systems and hyperbolic grid systems. It should be pointed out again that in ADAPTGD the same input control function has been employed to redistribute the inner boundary points as well as the outer boundary points for generating an elliptic grid network.

The modification made to subroutine RHS (---) for a hyperbolic grid generation seems to have made the hyperbolic grid network competitive to the elliptic grid network. An axisymmetric transonic flow past a projectile is being solved with an elliptic grid system similar to the one shown in Figure 3(a) as well as with a hyperbolic grid system similar to that shown in Figure 4(a). The results obtained under the same conditions and at iteration number = 1000 show that both grid systems give the pressure coefficient distribution of the same order of accuracy. A straight ray grid system had also been used for the flow problem; however, a number of difficulties had been encountered, apparently due to large truncation errors resulted from high skewness of the grid system.

For the application of ADAPTGD, the required input data tape FOR007 for adaptive boundary grid point generation can be created in the computer program package for the governing equations of the flow problem. For example, in the axisymmetric thin-layer Navier-Stokes code, the tape FOR007 can be created in the main program of the package.

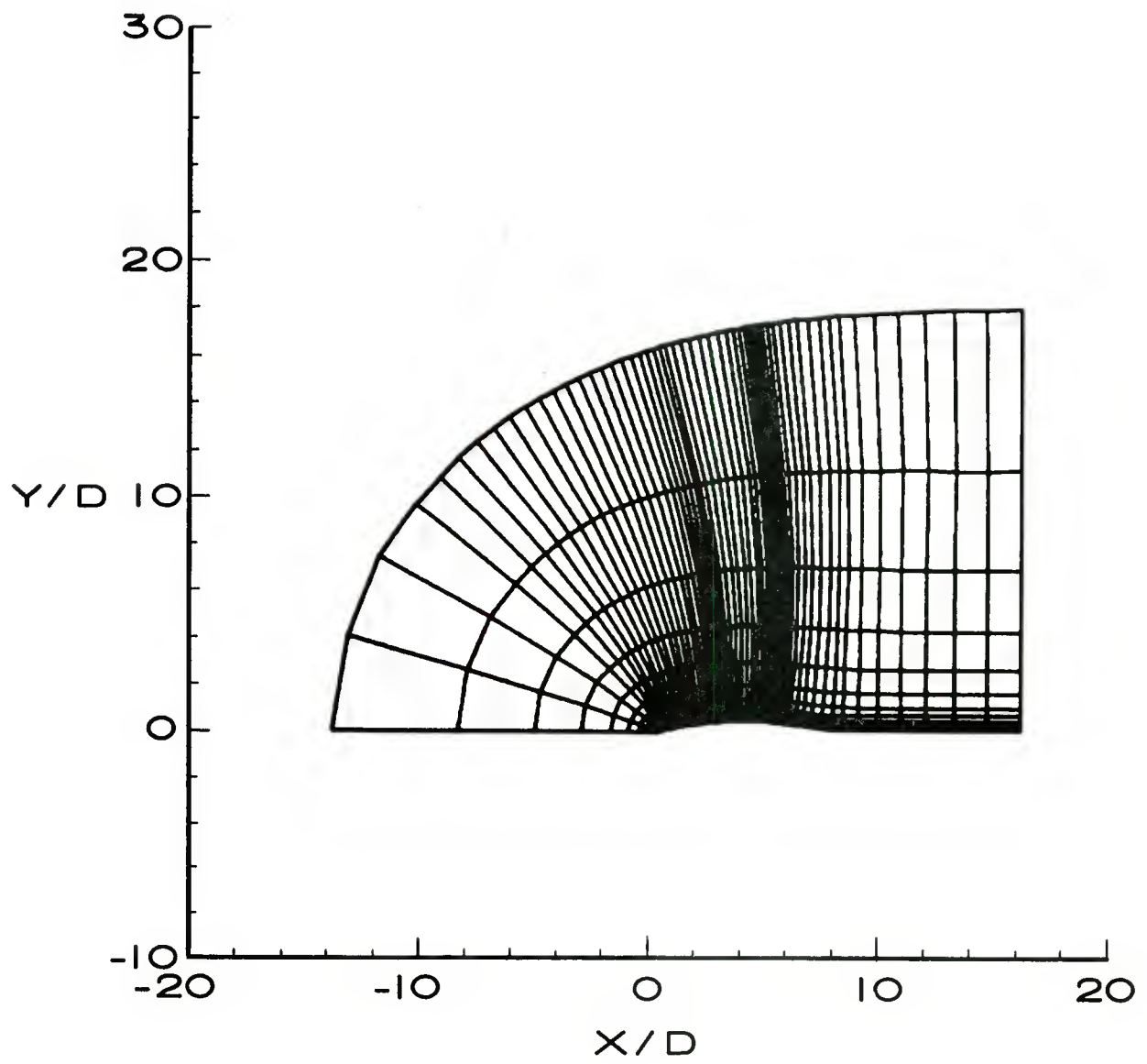


Figure 1. A Hyperbolic Grid Network Obtained from Original GRIDGEN

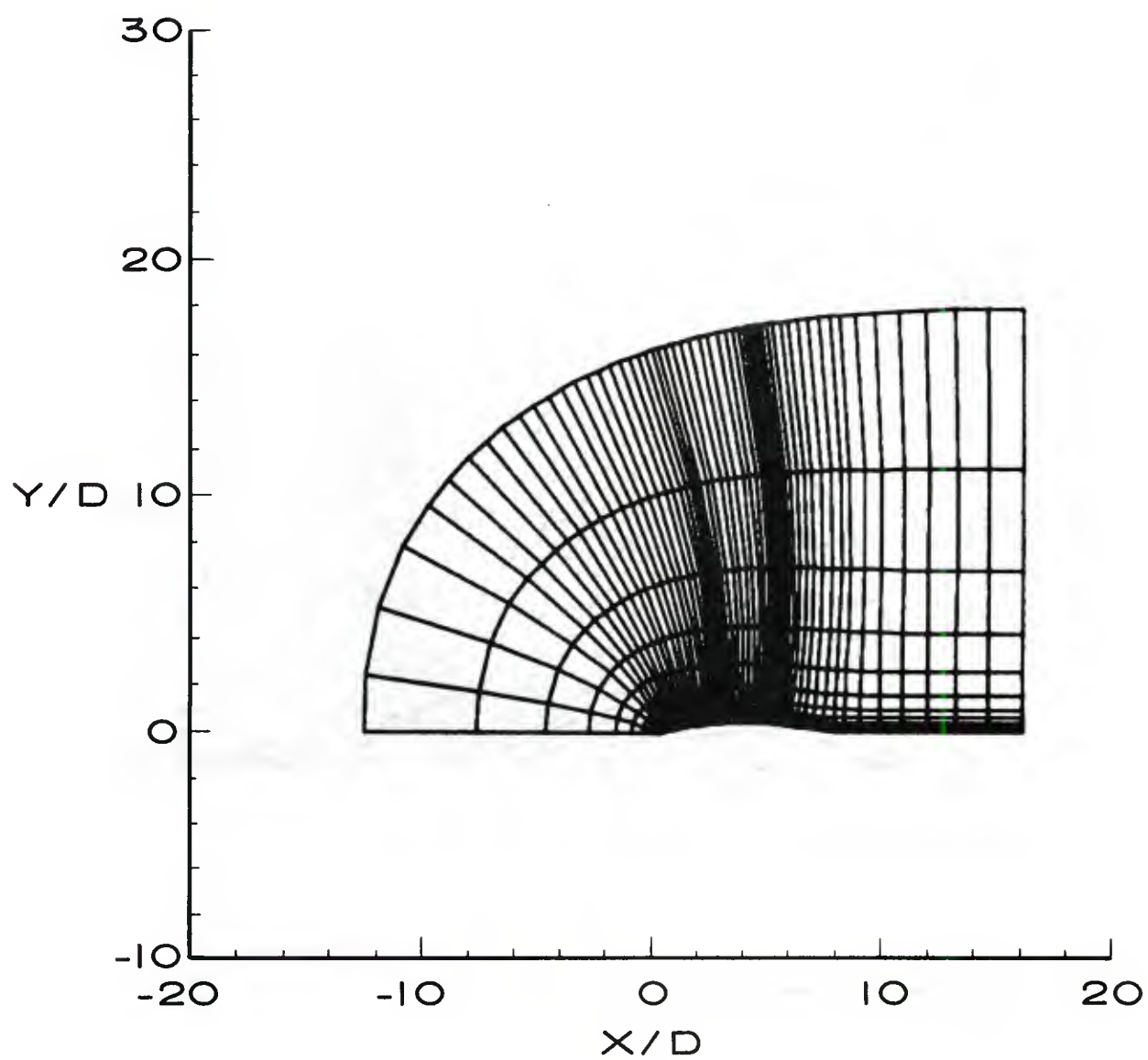


Figure 2. A Hyperbolic Grid Network Obtained from Modified GRIDGEN

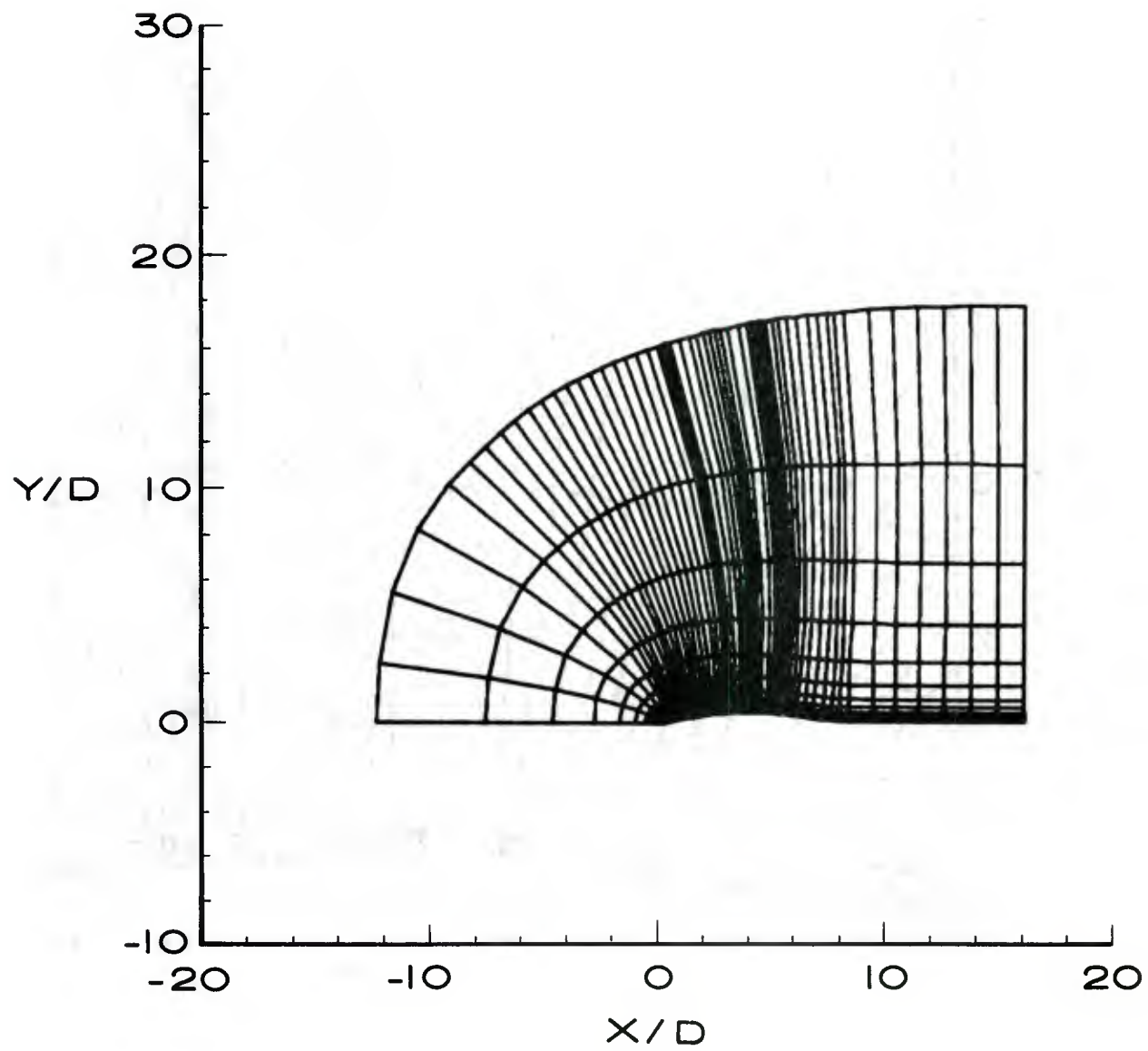


Figure 4a. A Hyperbolic Grid Using ADAPTGD - Total Flow Field

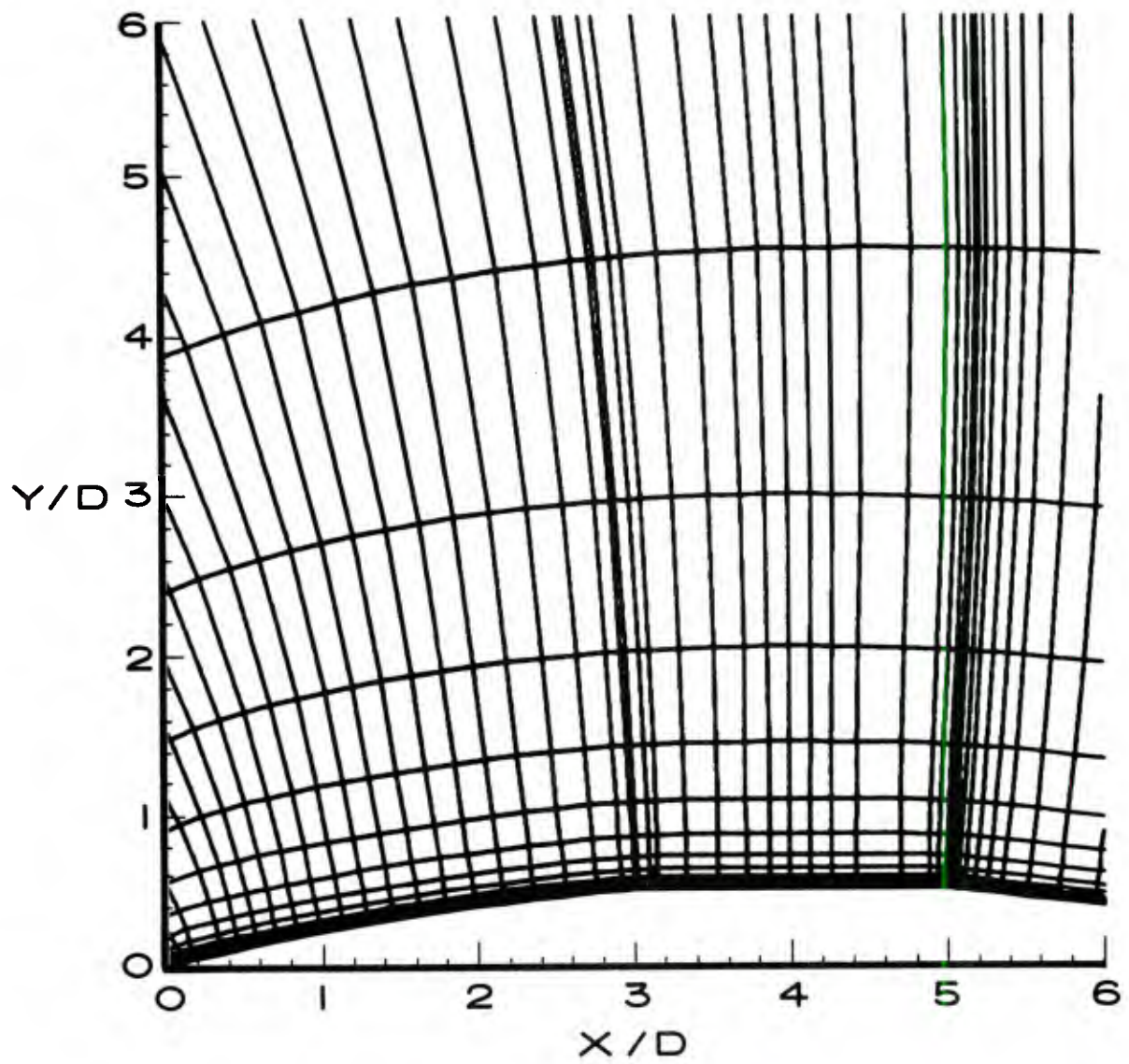


Figure 4b. Detailed Hyperbolic Grid Near Body Surface

TABLE 1. DATA FILE FOR007 FOR ADAPTIVE BOUNDARY GRID POINT DISTRIBUTION

J	XX(J)	YY(J)	XS(J)	YS(J)	FF(J)
1	0.3903E-01	0.5394E-05	-0.1800E+02	0.0000E+00	0.5133E+00
2	0.4903E-01	0.1305E-01	-0.1799E+02	0.1010E+00	0.3318E+00
3	0.9390E-01	0.2409E-01	-0.1799E+02	0.5755E+00	0.1522E+00
4	0.1701E+00	0.4258E-01	-0.1796E+02	0.1381E+01	0.2076E+00
5	0.2744E+00	0.6732E-01	-0.1789E+02	0.2485E+01	0.2075E+00
6	0.4033E+00	0.9702E-01	-0.1773E+02	0.3846E+01	0.1793E+00
7	0.5532E+00	0.1303E+00	-0.1743E+02	0.5414E+01	0.1396E+00
8	0.7208E+00	0.1661E+00	-0.1695E+02	0.7132E+01	0.1010E+00
9	0.9026E+00	0.2032E+00	-0.1623E+02	0.8928E+01	0.6669E-01
10	0.1095E+01	0.2404E+00	-0.1521E+02	0.1071E+02	0.3519E-01
11	0.1295E+01	0.2768E+00	-0.1390E+02	0.1238E+02	0.7091E-02
12	0.1499E+01	0.3117E+00	-0.1230E+02	0.1385E+02	-0.1890E-01
13	0.1703E+01	0.3444E+00	-0.1050E+02	0.1507E+02	-0.4226E-01
14	0.1905E+01	0.3743E+00	-0.8582E+01	0.1603E+02	-0.6226E-01
15	0.2100E+01	0.4012E+00	-0.6629E+01	0.1674E+02	-0.7971E-01
16	0.2285E+01	0.4248E+00	-0.4720E+01	0.1724E+02	-0.9396E-01
17	0.2457E+01	0.4450E+00	-0.2920E+01	0.1757E+02	-0.1058E+00
18	0.2612E+01	0.4619E+00	-0.1280E+01	0.1778E+02	-0.1154E+00
19	0.2747E+01	0.4756E+00	0.1533E+00	0.1791E+02	-0.1268E+00
20	0.2858E+01	0.4861E+00	0.1337E+01	0.1797E+02	-0.1472E+00
21	0.2943E+01	0.4937E+00	0.2231E+01	0.1799E+02	-0.1916E+00
22	0.2997E+01	0.4983E+00	0.2805E+01	0.1799E+02	-0.2839E+00
23	0.3017E+01	0.5000E+00	0.3016E+01	0.1800E+02	-0.3720E+00
24	0.3047E+01	0.5000E+00	0.3046E+01	0.1800E+02	-0.4440E+00
25	0.3141E+01	0.5000E+00	0.3142E+01	0.1800E+02	-0.4150E+00
26	0.3288E+01	0.5000E+00	0.3290E+01	0.1800E+02	-0.3793E+00
27	0.3476E+01	0.5000E+00	0.3479E+01	0.1800E+02	-0.3468E+00
28	0.3692E+01	0.5000E+00	0.3697E+01	0.1800E+02	-0.2998E+00
29	0.3925E+01	0.5000E+00	0.3932E+01	0.1800E+02	-0.2241E+00
30	0.4161E+01	0.5000E+00	0.4171E+01	0.1800E+02	-0.1311E+00
31	0.4391E+01	0.5000E+00	0.4402E+01	0.1800E+02	-0.5567E-01
32	0.4600E+01	0.5000E+00	0.4614E+01	0.1800E+02	-0.2570E-01
33	0.4778E+01	0.5000E+00	0.4793E+01	0.1800E+02	-0.4884E-01
34	0.4912E+01	0.5000E+00	0.4928E+01	0.1800E+02	-0.1325E+00
35	0.4990E+01	0.5000E+00	0.5006E+01	0.1800E+02	-0.3496E+00
36	0.5000E+01	0.5000E+00	0.5016E+01	0.1800E+02	-0.4080E+00
37	0.5010E+01	0.4987E+00	0.5026E+01	0.1800E+02	-0.4410E+00
38	0.5019E+01	0.4975E+00	0.5036E+01	0.1800E+02	-0.4734E+00
39	0.5034E+01	0.4957E+00	0.5050E+01	0.1800E+02	-0.5000E+00
40	0.5057E+01	0.4928E+00	0.5072E+01	0.1800E+02	-0.4621E+00
41	0.5095E+01	0.4882E+00	0.5108E+01	0.1800E+02	-0.4096E+00
42	0.5151E+01	0.4814E+00	0.5163E+01	0.1800E+02	-0.3527E+00
43	0.5230E+01	0.4716E+00	0.5241E+01	0.1800E+02	-0.2917E+00
44	0.5338E+01	0.4584E+00	0.5346E+01	0.1800E+02	-0.2240E+00
45	0.5478E+01	0.4412E+00	0.5485E+01	0.1800E+02	-0.1611E+00
46	0.5655E+01	0.4194E+00	0.5660E+01	0.1800E+02	-0.1022E+00
47	0.5875E+01	0.3925E+00	0.5878E+01	0.1800E+02	-0.4348E-01
48	0.6141E+01	0.3598E+00	0.6143E+01	0.1800E+02	-0.8539E-02
49	0.6458E+01	0.3208E+00	0.6460E+01	0.1800E+02	0.2258E-01
50	0.6832E+01	0.2749E+00	0.6833E+01	0.1800E+02	0.3760E-01

ETC.

TABLE 2. INPUT DATA FOR GENERATING FIGURE 3a BY ADAPTGD

1	4	25	44	44	53	53	60	ADAPT1
4	25	20	20					ADAPT2
0	0	18.						000001
60	28	0	18.		.00002			000002
-1	52	0	3					000003
1.		1.0						000004
0.		3.017	5.0		7.76722	.5	-7.	000005
18.88		0.025	4.58					000006
1	23	0.	3.017		.01	.02		000007
23	36	3.017	5.0		.03	.01		000008
36	52	5.0	7.76722		.010	.5		000009
1								000010
9	-1							000011
1								000012
7.76722	.16023	16.0		.16023				000013
1	9	7.76722	16.0	.5		1.5		000014
2	4							000015
-18.0	0.0	3.017	18.			90.	0.	000016
3.017	18.0	16.	18.			0.	0.	000017
1	23	0.0	31.69825	0.1		.21		000018
23	36	31.69825	33.69825	.03		.01		000019
36	52	33.69825	36.44847	.01		.5		000020
52	60	36.44847	44.68125	.5		1.5		000021
28	99	-1	0	1				000022
.00002	1.7							000023
1	25							000024
								000025
								000026

APPENDIX A
Partial Program Listing

APPENDIX A. PARTIAL PROGRAM LISTING

The implementation and modification made to the grid generation package GRIDGEN are given in this Appendix. Note that the additions made are given between the comment statements CCHSU while the deletion made in Subroutine RHS (---) are commented with CCH.

The Subroutine HADAPT (---) developed for redistribution of points along a curve and a general purpose interpolation program ATKN (---) are also given in the Appendix for references.

```

      PROGRAM MAIN
      COMMON JMAX, KMAX, JM, KM, NBOD, JBOD
      COMMON /BOUDY/ XX(100), YY(100), XS(100), YS(100), SS(100), S(100)
      1 , T(100), TS(100)
      COMMON /GRID/ X(80,60), Y(80,60)
CCHSU
      COMMON/PYHSU/IADAPT
      DIMENSION IE(8),FF(100)
      READ (5,100) IADAPT, NSADT
      READ (5,100) IE(1),IE(2),IE(3),IE(4),IE(5),IE(6),IE(7),IE(8)
C IADAPT=0 FOR REGULAR GRID GENERATION--GRIDGEN!
C IADAPT=1 FOR ADAPTIVE BOUNDARY GRID POINT GENERATION
C CONTROL DATA TO BE READ FROM FOR007
C NSADT IS THE NO. OF BOUNDARY SEGMENTS TO BE CONSIDERED FOR REDISTRIBUTION
C NSADT .LE. 4 IN THIS PROGRAM
C IE(K) ARE END NODAL NO. OF NSADT SEGMENTS. FOR EXAMPLE, THE FIRST SEGMENT
C IS BOUNDED WITH IE(1) AS THE INITIAL NODE AND ENDED WITH IE(2)
C IF NSADT = 3, THEN ANY NUMBER CAN BE ASSIGNED TO IE(7) AND IE(8)
CCHSU
C
C I3D = 0 FOR 2D, NO SPIN
C I3D = 1 FOR 3D, SYM3 HALF SPIN
C I3D = 2 FOR 3D, FULL3D FULL SPIN
C
C ISOLV = 0 FOR ELLIPTIC SOLVER
C ISOLV = 1 FOR HYPERBOLIC SOLVER
C
      READ (5,100) ISOLV,I3D,ND,LMAX
      WRITE (6,70) ISOLV,I3D,ND,LMAX
C
C READ JMAX,KMAX,IDAT,STOT,CDS FOR HYPGRD SOLVER
C IDAT = 0 FOR INPUT PTS OR ANALYTIC SHAPE
C IDAT = 1 FOR INPUT PTS ON "CARDS"
C IDAT = 2 FOR INPUT PTS ON XYFILE (TAPE7)
C STOT = -1. FOR CONSTANT DS
C
      READ (5,80) JMAX,KMAX,IDAT,STOT,CDS
      WRITE (6,90) JMAX,KMAX,IDAT,STOT,CDS
      JM=JMAX-1
      KM=KMAX-1
      IF (IDAT.EQ.0) GO TO 10
      IF (IDAT.EQ.1) CALL INPCD
      IF (IDAT.EQ.2) CALL XYFILE
      GO TO 20
10 CONTINUE
C
C DISTRIBUTE POINTS ALONG INNER BOUNDARY
      WRITE (6,110)
      CALL BODY
      READ (5,100) NFLAG
      IF (NFLAG.LT.0) GO TO 60
      READ (5,100) NCGRD,NCART
      WRITE (6,120) NCGRD,NCART

```

	IF (NCGRD.GT.0) CALL STING (NCGRD)	MAIN
	IF (NCART.GT.0) CALL CARTB (NCART)	MAIN
CCHSU	IF (IADAPT .EQ. 0) GO TO 19	
11	FORMAT(1H ,I5,5E15.7)	
	DO 12 I=1,JMAX	
12	READ (7,11) J,XX(I),YY(I),XS(I),YS(I),FF(I)	
	I1=1	
	DO 13 NS=1,NSADT	
	I2=I1+1	
	JI=IE(I1)	
	JE=IE(I2)	
	CALL HADAPT(FF,XX,YY,JI,JE)	
	IF (ISOLV .EQ. 1) GO TO 13	
	CALL HADAPT(FF,XS,YS,JI,JE)	
13	I1=I1+2	
19	CONTINUE	
CCHSU		
CCHSU	JMAX=JBOD	MAIN
	JM=JMAX-1	MAIN
	WRITE (6,130) JMAX	MAIN
20	WRITE (6,140)	MAIN
	DO 30 J=1,JMAX	MAIN
	WRITE (6,150) J,XX(J),YY(J)	MAIN
30	CONTINUE	MAIN
C		MAIN
	IF (ISOLV.EQ.0) CALL ELPGRD	MAIN
	IF (ISOLV.EQ.1) CALL INITIA	MAIN
	IF (ISOLV.EQ.1) CALL HYPGRD (STOT,CDS,IER)	MAIN
	IF (ISOLV.EQ.1.AND.IER.NE.0) GOTO 60	MAIN
C		MAIN
C	FORM 3D GRID. LMAX IS CIRCUMFERENTIAL DIRECTION	MAIN
	IF (I3D .EQ. 2) CALL SPNFUL (I3D,ND,LMAX)	MAIN
	IF (I3D .EQ. 1) CALL GSPIN (I3D,ND,LMAX)	MAIN
60	STOP	MAIN
C		MAIN
70	FORMAT (1H1,21H ISOLV, I3D, ND, LMAX,4I5)	MAIN
80	FORMAT (3I5,2F10.0)	MAIN
90	FORMAT (1H0,27HJMAX, KMAX, IDAT, STOT, CDS,3I5,2F10.5)	MAIN
100	FORMAT (8I5)	MAIN
110	FORMAT (/1H0,36H+++++ INNER BOUNDARY +++++)	MAIN
120	FORMAT (1H0,13H NCGRD,NCART ,2I5)	MAIN
130	FORMAT (1H0,21H FINAL VALUE OF JMAX ,I5)	MAIN
140	FORMAT (1H0,43H FINAL VALUES OF J,X,Y ALONG INNER BOUNDARY)	MAIN
150	FORMAT (1H ,I5,2F13.6)	MAIN
160	FORMAT (I5,6F12.5)	MAIN
	END	MAIN

```

SUBROUTINE OUTER (NSEGS,IOUTD)                                OUTER
COMMON JMAX, KMAX, JM, KM, NBOD, JBOD                        OUTER
COMMON /BOUDY/ XX(100), YY(100), XS(100), YS(100), SS(100), S(100) OUTER
1  , T(100), TS(100)                                          OUTER
COMMON /COMP/ X(100), Y(100)                                  OUTER
COMMON /ARRAY/ A(100), B(100), C(100), D(100), F(100), H(100) OUTER
CCHSU
COMMON/PYHSU/IADAPT
CCHSU
C
C THIS PROGRAM FORMS AN OUTER GRID BOUNDARY USING CONTIGUOUS CUBIC OUTER
C SEGMENTS. NUMBER OF SEGMENTS IS NSEGS. POINT AND SLOPE ARE INPUT AT OUTER
C THE ENDS OF A SEGMENT. SLOPE IS AN ANGLE IN DEGREES. PARAMETRIC OUTER
C CUBICS USED TO PERMIT ANY SLOPE (THETA = 90, -90, ETC). INITIAL OUTER
C LOGIC DETERMINES CUBIC COEFFICIENTS OF EACH SEGMENT. REMAINING OUTER
C LOGIC DISTRIBUTES POINTS ALONG OUTER BOUNDARY USING ARC LENGTH OUTER
C AS DISTRIBUTION FUNCTION. THUS TWO PARAMETRIC VARIABLES ARE USED. OUTER
C FINDING X.Y SO CUBIC SEGMENTS CAN BE DISJOINT IN SLOPE IS MESSY OUTER
C A SINGLE SPLINE INTERPOLATION CANNOT BE USED OVER THE COMBINED OUTER
C SEGMENTS BECAUSE OF POSSIBLE SLOPE DISCONTINUITY.          OUTER
C
C DIMENSION JA(8), JB(8)                                       OUTER
C DIMENSION CA0(8), CA1(8), CA2(8), CB0(8), CB1(8), CB2(8), CARC(8) OUTER
C DO 110 N=1,NSEGS                                              OUTER
C POINTS AND SLOPES, -90 .LE. THETA .LE. 90 DEGREES USED     OUTER
C READ (5,240) X0,Y0,X1,Y1,TH0,TH1                             OUTER
C WRITE (6,250) X0,Y0,X1,Y1,TH0,TH1                             OUTER
C RTH0=0.017453292*TH0                                          OUTER
C RTH1=0.017453292*TH1                                          OUTER
C
C .
C .
C .
190 CONTINUE                                                    OUTER
CCHSU
IF (IADAPT .EQ. 1) GO TO 220
CCHSU
C
C FORM PARAMETRIC ARRAYS, FROM DISTRIBUTED PARAMETRIC ARRAY,   OUTER
C USE IT TO DETERMINE X,Y WITHIN A OUTER SEGMENT CURVE.       OUTER
C SPLINE REQUIRES ABOUT 5 POINTS IN AN INTERVAL               OUTER
C S(1)=0.                                                       OUTER
C
C .
C .
C .
END                                                            OUTER

```

	SUBROUTINE RHS (K,SY,M,N)	RHS
	COMMON JMAX, KMAX, JM, KM, NBOD, JMOD	RHS
	COMMON /TRXE/ XXSI(100), YXSI(100), XADA(100), YADA(100)	RHS
	COMMON /GRID/ X(80,60), Y(80,60)	RHS
	COMMON /VOL/ V(100), VSTAR(100), DS(60)	RHS
	DIMENSION SY(160)	RHS
C	FILL RIGHT-HAND-SIDE VECTOR FOR HYPER SOLVER	RHS
	MSY=1	RHS
	DO 10 J=1,JMAX	RHS
	SY(MSY)=XXSI(J)*X(J,K)+YXSI(J)*Y(J,K)	RHS
	SY(MSY+1)=-YXSI(J)*X(J,K)+XXSI(J)*Y(J,K)+V(J)+VSTAR(J)	RHS
	MSY=MSY+2	RHS
10	CONTINUE	RHS
C	FRACTION OF EXPLICIT DISSIPATION THAT IS NOT PUT IN	RHS
C	IMPLICITLY	RHS
	EPS=.02	RHS
C	CAUTION -- EPS IS ALSO SET IN SUBROUTINE MATRX	RHS
CCH	JMM=JM-1	RHS
CCH	DO 20 J=3,JMM	RHS
CCH	MSY=2*J-1	RHS
CCH	SCALE=EPS*SQRT(XADA(J)**2+YADA(J)**2)	RHS
CCH	XX=X(J-2,K)-2.*(X(J-1,K)+X(J+1,K))+2.*X(J,K)+X(J+2,K)	RHS
CCH	YY=Y(J-2,K)-2.*(Y(J-1,K)+Y(J+1,K))+2.*Y(J,K)+Y(J+2,K)	RHS
CCH	SY(MSY)=SY(MSY)-SCALE*(XXSI(J)*XX+YXSI(J)*YY)	RHS
CCH	SY(MSY+1)=SY(MSY+1)-SCALE*(-YXSI(J)*XX+XXSI(J)*YY)	RHS
CCH20	CONTINUE	RHS
CCHSU		
	L=1	
	DO 30 J=1,JMAX	
	AJ=J	
	SCALE=EPS*SQRT(XADA(J)**2+YADA(J)**2)	
	IF (J .EQ. 1) GO TO 31	
	IF (J .EQ. JMAX) GO TO 32	
	XX=X(J+1,K)-2.*X(J,K)+X(J-1,K)	
	YY=Y(J+1,K)-2.*Y(J,K)+Y(J-1,K)	
	GO TO 35	
31	XX=2.*X(J+1,K)-2.*X(J,K)	
	YY=0.	
	GO TO 35	
32	XX=0.	
	YY=-2.*Y(J,K)+2.*Y(J-1,K)	
35	CONTINUE	
	SY(L)=SY(L)-SCALE*(XXSI(J)*XX+YXSI(J)*YY)	
	CHEN=(1.-60./AJ)	
	IF (J .LT. 4) CHEN=(1.-(100.-AJ*10.)/AJ)	
	SY(L+1)=SY(L+1)-SCALE*(-YXSI(J)*XX+XXSI(J)*YY)*CHEN	
30	L=L+2	
CCHSU		
	RETURN	RHS
	END	RHS

```

      SUBROUTINE HADAPT(FF,XX,YY,JI,JE)
C   FF(I) IS A FUNCTION OF BOUNDARY COORDINATE SUCH AS PRESSURE DISTRIBUTION
C   ON A PROJECTILE; ITS GRADIENT IS USED FOR REDISTRIBUTION OF THE
C   BOUDARY GRID POINTS
C   XX(I) AND YY(I) ARE (X,Y) OF THE GIVEN BOUDARY POINTS
C   JI IS THE INITIAL NODAL NUMBER WHILE JE IS THE END NODAL NUMBER
C   NOTE THAT THE BOUNDARY POINTS BETWEEN I=JI AND I=JE ARE TO BE REDISTRIBUTED
      DIMENSION FF(100),XX(100),YY(100),SX(100),SY(100),SF(100),FO(10
10),DS(100),TX(100),TY(100),TF(100),DT(99),G(99),W(99),XO(100)
      N=JE-JI
      NE=N+1
      IF (N .GT. 99) GO TO 120
C   INO IS THE NUMBER OF ITERATION FOR REDISTRIBUTION
      INO=3
      ITER=0
      DO 10 J=1,NE
        K=JI-1+J
        FO(J)=FF(K)
        XO(J)=XX(K)
        SF(J)=FF(K)
        SX(J)=XX(K)
10    SY(J)=YY(K)
        TF(1)=SF(1)
        TX(1)=SX(1)
        TY(1)=SY(1)
        TF(NE)=SF(NE)
        TX(NE)=SX(NE)
        TY(NE)=SY(NE)
20    CONTINUE
C   BW IS THE WEIGHT PARAMETER FOR THE GRADIENT OF FF
C   THE EFFECT OF THE GRADIENT ON REDISTRIBUTION INCREASES WITH INCREASING BW
      BW=5.0
      ST=0.
      WT=0.
      DO 30 J=1,N
        J1=J+1
        DS(J)=SQRT((SX(J1)-SX(J))**2+(SY(J1)-SY(J))**2)
        ST=ST+DS(J)
        G(J)=(SF(J1)-SF(J))/DS(J)
        W(J)=1./(1.+BW*ABS(G(J)))
30    WT=WT+W(J)
      ALPHA=ST/WT
      DO 40 J=1,N
40    DT(J)=ALPHA*W(J)
      TJ=0.
      SK=0.
      K=0

```

```

      DO 80 J=1,N-1
      J1=J+1
      TJ=TJ+DT(J)
50    K=K+1
      SK=SK+DS(K)
      IF (TJ .GE. SK) GO TO 50
      SK=SK-DS(K)
      R=(TJ-SK)/DS(K)
      K1=K+1
      TX(J1)=SX(K)+R*(SX(K1)-SX(K))
      TY(J1)=SY(K)+R*(SY(K1)-SY(K))
      TXI=TX(J1)
      TF(J1)=ATKN(XO,FO,NE,2,TXI)
      K=K-1
80    CONTINUE
81    FORMAT(1H1,'*** BW = ', F8.4)
      WRITE(6,81) BW
82    FORMAT(1H0,'J',9X,'DS',9X,'DT',9X,'SF',9X,'TF',9X,'SX',9X,'TX')
83    FORMAT(1H ,I3,6E12.4)
      WRITE(6,82)
      DO 84 J=1,N+1
84    WRITE(6,83) J,DS(J),DT(J),SF(J),TF(J),SX(J),TX(J)
      ITER=ITER+1
      IF (ITER .GT. INO) GO TO 100
      DO 90 J=2,N
      SF(J)=TF(J)
      SX(J)=TX(J)
90    SY(J)=TY(J)
      GO TO 20
100   DO 110 J=2,N
      K=JI-1+J
      XX(K)=TX(J)
110   YY(K)=TY(J)
      RETURN
120   WRITE(6,130)
130   FORMAT(1H1,'***** NO. OF POINTS EXCEEDS THE DIMENSION *****')
      STOP
      END

```

```

      FUNCTION ATKN(X,Y,N,K,XI)
C   AITKEN INTERPOLATING FUNCTION
C   X(I),I=1,N,--INDEPENDENT VARIABLE IN ASCENDING OR DESCENDING ORDER
C   Y(I)--TABLE OF DEPENDENT VARIABLE
C   K--DEGREE OF INTERPOLATION DESIRED; K .LE. 12
C   XI--X-VALUE WHERE THE INTERPOLATION IS DESIRED
      DIMENSION X(N),Y(N),XX(13),YY(13)
      DATA KMAX/12/
      IF (K .GT. KMAX .OR. K .LE. 0) GO TO 300
      K1=K+1
      IF (X(N)-X(1)) 100,10,10
10  IF (XI-X(1)) 20,20,30
20  LL=0
      GO TO 200
30  IF (X(N)-XI) 40,40,50
40  LL=N-K1
      GO TO 200
50  LL=1
      LU=N
60  IF (LU-LL-1) 180,180,70
70  LI=(LL+LU)/2
      IF (X(LI)-XI) 80,80,90
80  LL=LI
      GO TO 60
90  LU=LI
      GO TO 60
100 IF (XI-X(1)) 120,20,20
120 IF (X(N)-XI) 130,40,40
130 LL=1
      LU=N
140 IF (LU-LL-1) 180,180,150
150 LI=(LL+LU)/2
      IF (X(LI)-XI) 160,170,170
160 LU=LI
      GO TO 140
170 LL=LI
      GO TO 140
180 LL=LL-(K1+1)/2
      IF (LL) 20,200,190
190 IF (LL+K1-N) 200,200,40
200 DO 210 I=1,K1
      I1=LL+I
      XX(I)=X(I1)-XI
210 YY(I)=Y(I1)
      DO 220 I=1,K
      DO 220 J=I,K
220 YY(J+1)=(1.0/(XX(J+1)-XX(I)))*(YY(I)*XX(J+1)
      1-YY(J+1)*XX(I))
      ATKN=YY(K1)
      RETURN
300 WRITE(6,301) K
301 FORMAT('1','POLYNOMIAL OF DEGREE K =',I3,2X,'IS
      1INCORRECT FOR THE FUNCTION SUBPROGRAM ATKN')
      RETURN
      END

```

DISTRIBUTION LIST

<u>No. of</u> <u>Copies</u>	<u>Organization</u>	<u>No. of</u> <u>Copies</u>	<u>Organization</u>
12	Administrator Defense Technical Info Center ATTN: DTIC-DDA Cameron Station Alexandria, VA 22314	1	Director US Army Air Mobility Research and Development Laboratory Ames Research Center Moffett Field, CA 94035
1	Commander US Army Materiel Development and Readiness Command ATTN: DRCDMD-ST 5001 Eisenhower Avenue Alexandria, VA 22333	1	Commander US Army Communications Research and Development Command ATTN: DRSEL-ATDD Fort Monmouth, NJ 07703
10	Commander US Army Armament Research and Development Command ATTN: DRDAR-TDC DRDAR-TSS DRDAR-LCA-F Mr. D. Mertz Mr. E. Falkowski Mr. A. Loeb Mr. R. Kline Mr. S. Kahn Mr. S. Wasserman Mr. H. Hudgins Dover, NJ 07801	1	Commander US Army Electronics Research and Development Command Technical Support Activity ATTN: DELSD-L Fort Monmouth, NJ 07703
1	Commander US Army Armament Materiel Readiness Command ATTN: DRSAR-LEP-L Rock Island, IL 61299	2	Commander US Army Missile Command ATTN: DRSMI-R DRSMI-RDK Mr. R. Deep Redstone Arsenal, AL 35898
1	Director US Army Armament Research and Development Command Benet Weapons Laboratory ATTN: DRDAR-LCB-TL Watervliet, NY 12189	1	Commander US Army Missile Command ATTN: DRSMI-YDL Redstone Arsenal, AL 35898
1	Commander US Army Aviation Research and Development Command ATTN: DRDAV-E 4300 Goodfellow Blvd. St. Louis, MO 63120	1	Commander US Army Tank Automotive Command ATTN: DRSTA-TSL Warren, MI 48090
		1	Director US Army TRADOC Systems Analysis Activity ATTN: ATAA-SL White Sands Missile Range NM 88002
		2	Commandant US Army Infantry School ATTN: ATSH-CD-CSO-OR Fort Benning, GA 31905

DISTRIBUTION LIST

<u>No. of Copies</u>	<u>Organization</u>	<u>No. of Copies</u>	<u>Organization</u>
1	Commander US Army Research Office P. O. Box 12211 Research Triangle Park NC 27709	1	Director NASA Ames Research Center ATTN: MS-227-8 Dr. L. Schiff Moffett Field, CA 94035
1	Commander US Naval Air Systems Command ATTN: AIR-604 Washington, D. C. 20360	1	Nielsen Engineering & Research, Inc. ATTN: Dr. S. Stahara 510 Clyde Avenue Mountain View, CA 94043
3	Commander David W. Taylor Naval Ship Research and Development Center ATTN: Dr. S. de los Santos Dr. Joanna Schot Mr. Stanley Gottlieb Bethesda, Maryland 20084	2	Sandia Laboratories ATTN: Technical Staff, Dr. W.L. Oberkampff Aeroballistics Division 5631, H.R. Vaughn Albuquerque, NM 87115
4	Commander US Naval Surface Weapons Center ATTN: Dr. T. Clare, Code DK20 Mr. P. Daniels Mr. D. A. Jones III Mr. L. Mason Dahlgren, VA 22448	1	Massachusetts Institute of Technology ATTN: Tech Library 77 Massachusetts Avenue Cambridge, MA 02139
4	Commander US Naval Surface Weapons Center ATTN: Code 312 Dr. C. Hsieh Dr. W. Yanta Dr. T. Zien Mr. R. Voisiniet Silver Spring, MD 20910	1	Stanford University Department of Aeronautics and Astronautics ATTN: Prof. J. Steger Stanford, CA 94305
1	Commander US Naval Weapons Center ATTN: Code 3431, Tech Lib China Lake, CA 93555	1	University of California, Davis Department of Mechanical Engineering ATTN: Prof. H.A. Dwyer Davis, CA 95616
1	Director NASA Langley Research Center ATTN: NS-185, Tech Lib Langley Station Hampton, VA 23365	1	University of Delaware Mechanical and Aerospace Engineering Department ATTN: Dr. J. E. Danberg Newark, DE 19711

DISTRIBUTION LIST

<u>No. of Copies</u>	<u>Organization</u>
1	University of Florida ATTN: Dr. J.E. Milton P.O. Box 1918 Eglin AFB, FL 32542
1	University of Florida ATTN: Prof. C-C Hsu 231 Aerospace Engineering Bldg Gainesville, FL 32611
<u>Aberdeen Proving Ground</u>	
	Dir, USAMSAA ATTN: DRXSY-D DRXSY-MP, H. Cohen
	Cdr, USATECOM ATTN: DRSTE-TO-F
	Dir, USACSL, Bldg. E3516, EA ATTN: DRDAR-CLB-PA DRDAR-CLN DRDAR-CLJ-L

USER EVALUATION OF REPORT

Please take a few minutes to answer the questions below; tear out this sheet, fold as indicated, staple or tape closed, and place in the mail. Your comments will provide us with information for improving future reports.

1. BRL Report Number _____

2. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which report will be used.)

3. How, specifically, is the report being used? (Information source, design data or procedure, management procedure, source of ideas, etc.) _____

4. Has the information in this report led to any quantitative savings as far as man-hours/contract dollars saved, operating costs avoided, efficiencies achieved, etc.? If so, please elaborate.

5. General Comments (Indicate what you think should be changed to make this report and future reports of this type more responsive to your needs, more usable, improve readability, etc.) _____

6. If you would like to be contacted by the personnel who prepared this report to raise specific questions or discuss the topic, please fill in the following information.

Name: _____

Telephone Number: _____

Organization Address: _____
